Introduction to new methods of static and dynamic pull testing of rock bolts and cable bolts

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INTRODUCTION TO NEW METHODS OF STATIC AND DYNAMIC PULL TESTING OF ROCK BOLTS AND CABLE BOLTS

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ABSTRACT: Despite the decades where application of rock bolts and tendons have been the main supporting system for ground in both hard and soft rock formations in mines and tunnels, there remains significant uncertainty about the behaviour and performance of these easy-to-use technologies. The importance of effective support is paramount with regard to ground seismicity and dynamic loading cause by outburst, rock burst and rock blasting activities. The evaluation and assessment of the axial loading and shear behaviour of rock bolts enables the design of a credible methodology for effective and sound ground reinforcement. This paper deals mainly with the development of a pull testing rig that is used for the testing of cable bolts and tendons under both static and dynamic conditions. The dynamic test was carried out by the drop hammer impact test. It was found that a 30 % greater pulling force is needed for the pull testing of cables statically in comparison with the dynamic impact test, this being in agreement with past numerical studies.

INTRODUCTION

Safe mining and tunnelling relies on a sound and economically viable support system for effective ground control. Hence, the design and installation of the supporting system should carefully tiptoe on the verge of safety and cost efficiency. This has led to continuous studies in support system technologies in underground space structures during the last few decades. Among the common supporting systems (from old-fashioned wooden frames to the masonry arch, to the steel arch and to the most modern concrete segments) the combination of anchor bolts (rock bolts and cable bolts and), wire mesh and shotcrete has been one of the popular supporting systems available due to their following advantages:

- Not constrained by underground excavation shape
- Swift installation after excavation
- Does not occupy operational area (optimum excavation profile)
- Provides active support and safer strata control by pretension force, and
- Economical in comparison to other modern systems

Several types of rock bolts, FRPs and cable bolts are marketed in Australia and are used in different ground conditions. Solid rock bolts are used mainly for primary support while tendons are used for both primary and secondary supports. Some of the basic and more frequent types of rock bolts and tendons are classified in Table 1.

Over the past several decades a number of studies have covered the performance of rock bolts and tendons under different loading conditions. Tendons are mainly subjected to axial or shear load or the combination of both; however, available experimental studies and numerical modellings are addressed separately. In spite of studies undertaken and widely reported as to the behaviour of tendons under static loading condition, only a handful were reported on the dynamic testing of tendons, particularly under axial conditions. These include the works of Habenicht's (1965) , Otuonye (1988), Ortlepp and Stacey, (1994) and Tennent, et al., (1995). These studies were based mainly on field measurements of controlled blasting using geophones and strain gauges.

As one of the first experimental studies in 1977, Veesaert studied both the static and dynamic pull-out resistance of anchors buried in dry conditions and with the emphasis being placed on the profile of the

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uplifted sand subjected to static and dynamic loadings of embedded half anchors. Their study revealed that both the static and dynamic loading of the anchors does not significantly affect the failure of the surface profile, eventhough, the depth of embedment can alter the geometry of failure. Veesaert's tests showed a greater pull-out resistance with the dynamic test compared with the static test and the reasons provided were convincible, based on the theory of inertial forces and increased shear resistance under dynamic motions (Veesaert 1977).

Table 1 Common Australian rock bolts and tendons

Rock bolts		Cable bolts	
			
Cross section		Cross section	
Solid steel		Nut caged	
Hollow		Plain	
FRP		Indented	

Fundamental studies by the end of the twentieth century are numerous and some notables are worth mentioning, these include the works of Ortlepp and Stacey, (2000): Kabwe and Wang (2015), Thenevin et al. (2017); Wang and Cai (2017), Aziz, et al (2016, 2019, 2020); Khaleghparast,et al., (2020), S Chen, Saydam, and Hagan (2018) and Wang et al. (2018). In the most recent laboratory development studies, Thenevin (2017) and Chen *et al.* (2017) introduced new laboratory equipment for static pull-out testing. Thenevin, *et al.,* (2017) designed a double embedment pull-out test rig to study the effect of various parameters including the confining pressure, embedment length and roughness of the borehole (Figure 1). In this study, three types of rock bolt, smooth, ribbed rebar and Fibre Reinforced polymer (FRP) bolt were used. Additionally, three other types of 23 mm diameter seven-strand Reflex cable, 16.2 mm diameter mini-cage cable bolt and a special cable for Polish coal mines were tested. The unique design of the hydraulic confinement pressure of up to 25 MPa and using rock samples instead of concrete samples added to the value of this research. The hydraulic confinement system was capable of controlling either confinement or stiffness of the medium during the test. Even though their results with these rock bolts would follow a reasonable trend and satisfied the theory of the pull test, however, experiments carried out on cable bolts, including mini-caged cables were not successful, as major cracks in the rock samples did not allow for the investigation of the effect of confinement.

Also Chen (2016) and Hagan, *et al.* (2017) studied the performance of tendons under static pull-out loading conditions. In this study, a modified version of the double embedment pull-out test (Figure 2) was used and evaluated the effect of several parameters including media strength, cable type, the confinement stiffness and embedment length.

The abovementioned studies have been carried out on static pull-out loading of tendons only, however, the dynamic response of tendons under the same loading condition remains to be determined. Accordingly, this study describes a new pull-out rig which is capable of pull testing rock bolts and tendons under both static and dynamic test conditions.

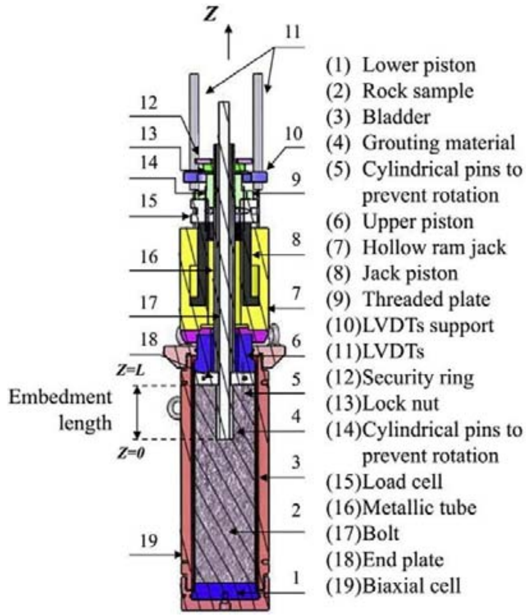


Figure 1: static pull test rig using rock samples as host medium (Thenevin et al. 2017)

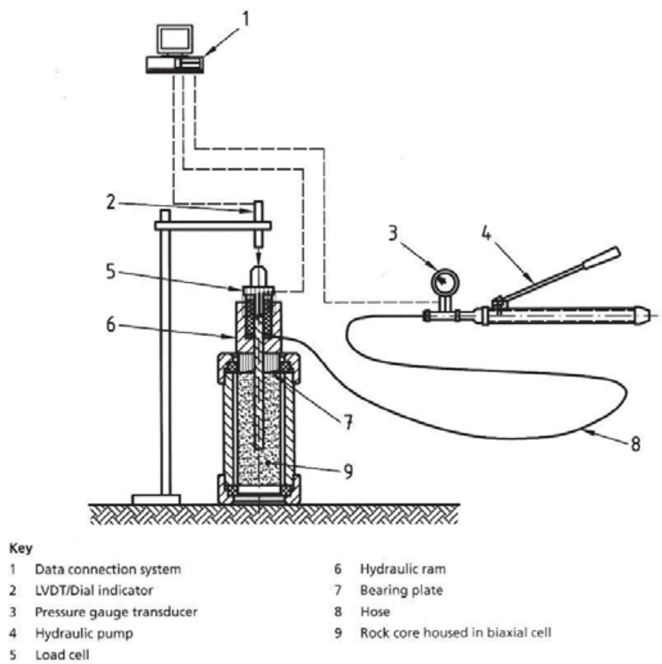
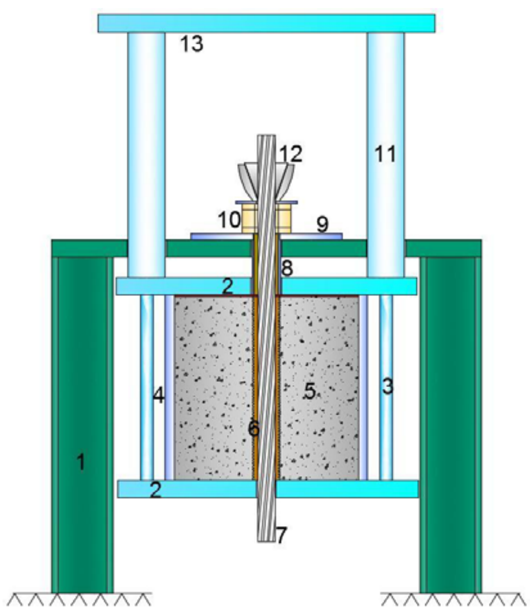


Figure 2: Static pull test rig design (Hagan and Li 2017)

TESTING MECHANISM

Generally, two methods are used for the pull testing of both rock bolts and wired tendons; single embedment and double embedment (Aziz, 2004; Cao et al. 2013; Ma et al. 2016). Double embedment is the common pull-out test method in which the whole length of the tested cable is encapsulated in the double embedment within different encapsulation types and lengths (Thomas 2012, Aziz, et al., 2015). In this particular study, tendons are encapsulated by cementitious grout in concrete media, which is closely simulating the real field conditions for bolting. 40 MPa cylindrical concrete samples (300 mm in diameter and 450 mm in height) are confined externally by 30 mm thick half-cylinder steel clamps. The two halves are bolted to each other to clamp and confine the concrete firmly to prevent possible radial cracks in the concrete samples. A tendon is inserted in a 35 mm riffled borehole in the centre of the concrete sample and the gap between the tendon and concrete is filled by cementitious grout.

Unlike previously presented methods, the new design has been based on push-to-pull loading of the tendon out of the grouted concrete sample. Figure 3 shows the main elements of the new pull-out test rig. The static or dynamic load can be applied downward on the loading plate. The applied load is transferred to a vertical confining plate by four connected load transferring shafts. In additional to lateral confinement the concrete sample is held vertically firm by 30 mm vertical confining plates. The vertical confining load is also adjustable by using bolts and confining rods up to 60 N.m. The top extruded end of the tendon is covered by an anti-rotation confining tube (100 mm long), the chamfered edges of the tube are firmly gripped by the anti-rotation plate. Eventually, the hollow load cell records the axial load carried by the barrel and wedge.



1 Fixed base body frame
2 Vertical confining plates
3 Confinement rods
4 Radial confinement cylinder
5 Concrete sample
6 Grout
7 Tendon or rock bolt
8 Anti-rotation confining tube
9 Anti-rotation plate
10 Hollow load cell
11 Load transferring shafts (four)
12 Barrel and Wedge
13 Loading plate

Figure 3. Simplified schematic drawing of new static and dynamic pull-out test rig

The rig has been designed to tolerate a 1000 kN static load. Two different loading rigs are used for loading in either static or dynamic modes. A hydraulic sixty-tonne compression load frame shown in Figure 4a applies the static load with a minimum rate of loading being between 0.5 mm/min and 25 mm/min. For dynamic loading the load can be applied by a free falling impact drop hammer as shown in Figure 4b. The hammer weights 600 kg and the drop height is 3.5 m. In other words, roughly 20 kJ of potential energy can be applied in a fraction of a second at an approximate speed of 8 m/s.

Possible modes of failure in this study include:

- Deboning of cable and grout: According to the design, this is the most probable failure mode.
- Cable failure outside of the concrete: if the bond between the grout and cable inside the concrete sample remains sound, then failure occurs between the anti-rotation grout and concrete sample.
- Cable failure inside the barrel and wedge: the main applied load on the cable is carried by the barrel and wedge. This may result in stress concentration on the B&W and possible failure of the cable or B&W as part of the whole supporting system.

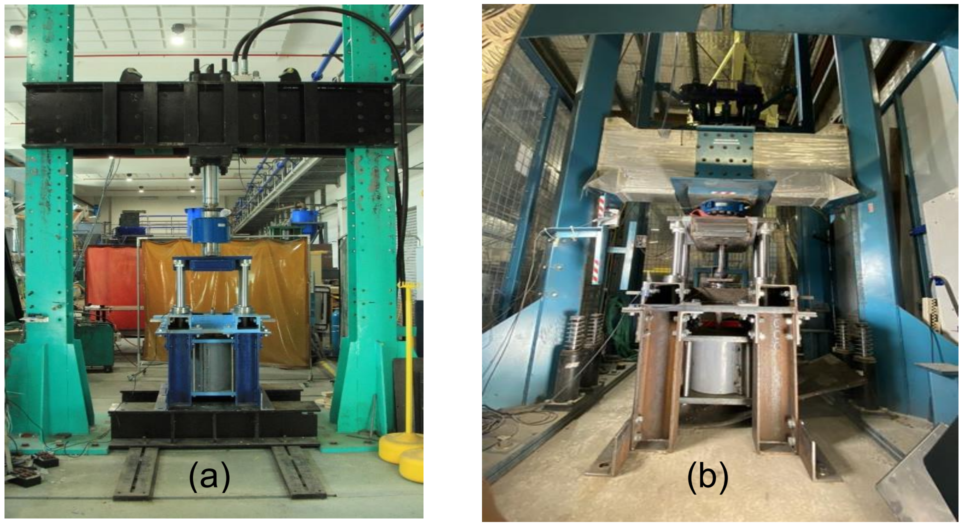


Figure 4: (a) Pull test rig ready for static test by 60-ton hydraulic jack and (b) Pull test rig ready for dynamic test by impact drop hammer

Concrete cylinder casting

The circular concrete blocks are cast in 300 mm diameter Formatube cardboard cylinders. Two 300 mm and one 450 mm cardboard lengths are cut and assembled in a specially prepared wooden frame for the concrete pour as shown in Figure 5. During the casting of the concrete and production of the central hole for cable installation, a conduit wrapped with 8 mm PVC tube is held vertically along the mould to precast a rifled hole through the centre of the concrete blocks. Once the concrete was poured it was left to set and harden, the steel conduit as well as the PVC tube are removed in similar fashion as reported by Aziz et al. 2017 in ACARP project report C24012.

After the concrete pour, samples are cured for 28 days in a purpose-built water tank to reach their maximum strength. In the next step, each tendon is encapsulated vertically in the cast center hole. As soon as the grout sets, radial clamps (two half) and axial confinement plates are placed around the concrte cylinder and bolted together. Flexible rubber matts are inserted between the top and bottom steel plates and the concrete sample to minimise the effect of concrete surface roughness.

Figure 5. Concrete sample preparation

RESULTS AND DISCUSSION

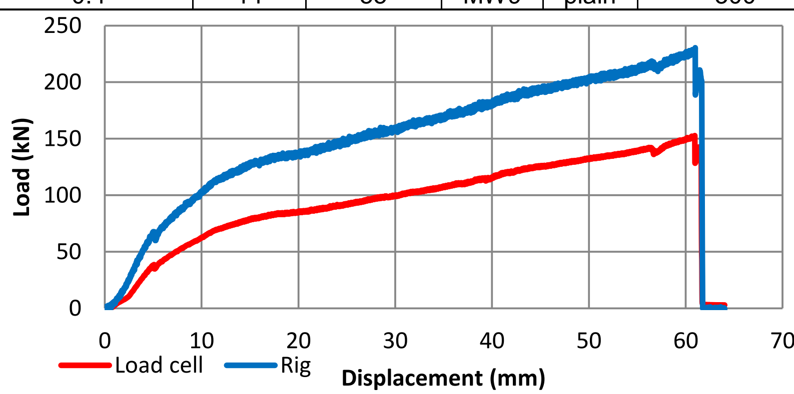
The first set of preliminary static and dynamic tests were carried out using MW9 Megabolt cables. The purpose of the test was for calibration and justification of the designed rig. Figure 6Figure shows test specifications and results of the static test.

The static test results revealed the contribution of each of the cable and B&W in simultaneous load distribution. This can be found from the gentle slope of the graph in the first 10 mm. Normally the first 5 mm of the loading graph presents the fully elastic strength of the grout against the pull-out test. This is while in existence of B&W, flexible deformation of the wedge inside the barrel leads to the smoother force distribution on the system. The second test evaluates the behaviour of the same cable under impact dynamic loading. A drop hammer applies an equivalent energy of 14.7 kJ by free falling from a height of 2.5 m. Test specifications and results have been summed up in Figure 7. As shown in the graph of impact load versus time in the mentioned figure, there are three stages of loading. The first peak load (1) is the inertia effect, which is the inertia transferring force from the moving object to the stationary object. The second stage (2) is known as the load bearing of the tendon, when the sample is moving downward along with the impacting hammer, which creates a low-frequency oscillation in the load-time curve. According to the conservation of momentum, the momentum before collision equals the momentum after collision. The third peak (3) is the pull-out load after post peak loading.

CONCLUSIONS

A universal new testing rig has been developed for pull testing of rock bolts and tendons under static and dynamic conditions. The availability of this rig together with the double shear testing facilities, available in the same laboratory would permit a better understanding of the effectiveness of the rock bolts and flexible tendons in underground and surface structures undergoing seismic activities. The rig is a versatile tool which can be used for testing the various ground support reinforcement tools of both rock bolts and cable bolts, thus enabling the selection of reinforcement units to suite the prevailing ground conditions particularly in locations where the effect of rock bursts and gas outburst may occur. Preliminary comparison of static and dynamic test results revealed that the dynamic pulling force is 30% lower than that of the force spent in pulling out the cable statically because of the absence of time related frictional force needed to pull out the cable; however, further experiments are required to verify this statement. The rig is a useful tool together with double shear rigs under one roof for testing and selecting the correct tendons effectively for given ground conditions, particularly when the ground is likely to be subjected to seismic activities, thus mitigating the effect or influence of rock burst.

Concrete		Grout			cable			Test
Strength (MPa)	Age (days)	Water/Cement ratio	Age (days)	Strength (MPa)	Type		Embedment length (mm)	Type
40	28	0.4	14	55	MW9	plain	300	Static 1mm/min

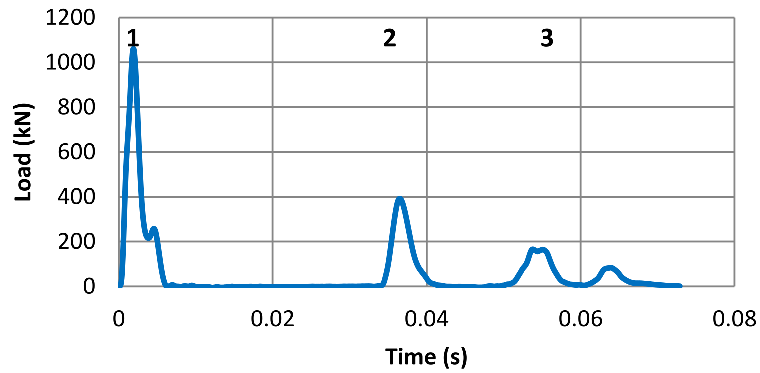


Test Outputs

Max applied load (kN)	Max load in cell (kN)	Max displacement (mm)	Absorbed energy (kJ)	Unit load (kN/mm)	Unit energy absorption (kJ/mm)
230.5	152.8	64	5.97	3.60	0.09

Figure 6: Specification and result of static test

Concrete		Grout			cable			Test
Strength (MPa)	Age (days)	Water/cement ratio	Age (days)	Strength (MPa)	Type		Embedment length (mm)	Type
40	28	0.4	14	55	MW9	plain	300	Dynamic 2.5m



Test Outputs					
Max rig load (kN)	Max load cell (kN)	Max displacement (mm)	Applied energy (kJ)	Unit load (kN/mm)	Unit energy absorption (kJ/mm)
400	-	124	14.7	3.25	0.119

Figure 7: Specification and result of dynamic test

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